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ABSTRACT

Electro-Discharge Machining (EDM) has found widespread application in the fabrication of Micro-Electro Mechanical Systems (MEMS), tool and mold industries and aerospace industries. The machining technique now plays an indispensable role in the fabrication of a wide variety of components. However due to rapid heating and cooling during machining, a thermally affected layer will form on the machined surface. A close inspection reveals the presence of many surface defects such as void, cracks, shallow crater and debris on this layer. Tungsten carbide (WC) with 15% of cobalt content is selected as the workpiece material and the copper tungsten as the electrode in this experiment. The electrodes are consisting in three different sizes are 3mm, 6mm and 8mm of diameter. Since EDM has been shown to be a versatile method for machining difficult-to-work materials, it is believed that the EDM process will open up an opportunity for the machining of tungsten carbide (WC). The aim of this study is to analyzes the machined surface in term of surface roughness that influenced by the different size of electrodes. After completion the experiment process, scanning electron microscope (SEM) will be employed to analyze the surface topography and the surface roughness tester will be used to measure the surface roughness on the machined surface.

ABSTRAK

Electro-Discharge Machine (EDM) telah ditemui secara meluas penggunaannya di dalam pembuatan Micro-Electro Mechanical Systems (MEMS), industri alat dan acuan, dan industri aeroangkasa. Pada masa kini, teknik memesinnya memainkan peranan yang penting di dalam pembuatan pelbagai komponen. Walaubagaimanapun pemanasan serta peyejukkan yang cepat semasa operasi pemesinan dijalankan akan mengakibatkan terbentuknya satu lapisan di atas permukaan ini. Satu penyemakan hampir telah mendedahkan bahawa banyak kecacatan hadir di atas lapisan ini seperti lopak, keretakan, kawah cetek dan puing. Tungsten karbida (WC) dengan 15% kandungan kobalt dipilih sebagai bahan kerja dan tungsten tembaga sebagai elektrod dalam eksperimen ini. Elektrod ini terdiri daripada tiga saiz yang berbeza iaitu 3mm, 6mm, dan 8mm. Semenjak EDM menunjukkan satu kaedah yang serba boleh untuk memesin bahan kerja yang sukar, ia dipercayai boleh membuka peluang untuk memesin tungsten karbida (WC). Kajian ini adalah bertujuan untuk menganalisis permukaan yang dimesin dalam istilah kekasaran permukaan yang dipengaruhi oleh pengunaan saiz elektrod yang berbeza. Selepas eksperimen siap dijalankan, mikroskop pengesanan elektron (SEM) akan digunakan untuk menganalisis topografi permukaan dan penguji kekasaran permukaan akan digunakan untuk mengukur kekasaran permukaan yang dimesin.

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t_i	Pulse on-time
t_0	Pulse off-time
R_a	Surface roughness
I	Intensity
A	Current

LIST OF ABBREVIATIONS

EDM	Electro-discharge machine
MEMS	Micro-Electro Mechanical Systems
WC	Tungsten Carbide
SEM	Scanning electron microscope
MRR	Material removal rate
DC	Direct current
HAZ	Heat affected zone
ER	Electrode wear

CHAPTER 1

INTRODUCTION

1.1 Project Background

Electrical discharge machining (EDM) is a process that is used to remove metal through the action of an electrical discharge of short duration and high current density between the tool and the workpiece. It has been proven to be especially valuable in the machining of super-tough, electrically conductive materials such as the new space-age alloys. These metals would have been difficult to machine by conventional methods, but EDM has made it relatively simple to machine intricate shapes that would be impossible to produce with conventional cutting tools. This machining process is continually finding further applications in the metal machining industry. Although the application of EDM is limited to the machining of electrically conductive workpiece materials, the process has the capability of cutting these materials regardless of their hardness or toughness [1].

The material used in this experiment is tungsten carbide (WC) with 15% of cobalt content. Tungsten carbide is an important tool and die material mostly because of its high hardness, strength and wear resistance over a wide range of temperature. It has high specific strength and cannot be processed easily by conventional machining techniques. Since EDM has been shown to be a versatile method for machining difficult-to-work materials, it is believed that the EDM process will open up an opportunity for the machining of tungsten carbide. As such, extensive study on the effect of machining parameters on the machining characteristics in EDM of tungsten carbide should be called for [2].

This experiment will perform at constant parameter of EDM with the different size of electrode and then it will be compare to get fine machined surface in cutting WC. After EDM operation, the scanning electron microscopy (SEM) will be employed to analyze the machined surface. The surface topography reveals that the surface roughness is caused by an uneven fusing structure, globules of debris, shallow craters, pockmarks, voids and cracks [3]. Then, the machined workpiece surface will be measured by using the surface roughness tester to analyze the surface roughness. The surface roughness is influenced by the size, appearance and depth of the electrode discharge [3]. The current also reveal that some of the surface crack distribution is influenced by the machining parameters, the electrode diameter and the material conductivity [3].

1.2 Objective

i) To investigate relationship between the electrode size and machined surface of tungsten carbide (WC) in the EDM machining process.

1.3 Project Scopes

The research scope is limited to:

i) EDM Die Sinking (Sodick AQ55L) will be used for the whole experiment.
ii) Tungsten carbide with 15% of cobalt content is selected as the workpiece.
iii) The parameter that will be set up at the constant rate are pulse duration, peak current, arc gap, duty cycle and intensity.
iv) The surface topography of tungsten carbide (WC) will be examined by using a scanning electron microscope (SEM).
v) The surface roughness of the workpiece will be measured by using a surface roughness tester (Perthometer S2 Mahr).

1.4 Problem Statement

In this experiment, tungsten carbide (WC) will be cut using EDM machine with different sizes of electrode at the constant selected parameter of EDM. The problem might interface in this experiment is when the large of size of electrode is used will attend to more roughness on the machined surface. Therefore this study were implemented to show how the surface roughness can be influenced by the different size of electrode and in order to get fine machined surface.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of EDM Machining

EDM has been an important manufacturing process for the tooling, mould and die industries for several decades. Currently, it is just as likely to be used for production quantities of aircraft, medical, and electronic parts, as for tooling and prototypes. Turbine disks for aircraft engines, and airfoil shapes for ground-based turbines are among its many current applications, which also encompass die cavities for large automotive body components such as narrow slots, turbine blades, and various intricate shapes [4]. Other major uses of the process include machining carbide stock and producing metal molds and dies for stamping, forging, and jewelry manufacture [5]. The process is finding an increasing industrial use due to the ability of producing geometrically complex shapes as well as its ability to machine hard materials that are extremely difficult to machine when using conventional process. There are two main types of EDM processes [6]:

i. Conventional EDM (Sinker EDM or Ram EDM)
ii. Wire EDM

The ability of EDM to machine hard materials that are extremely difficult to machine has made some researcher to categories and classified the machining processes as shown on Figure 2.1.

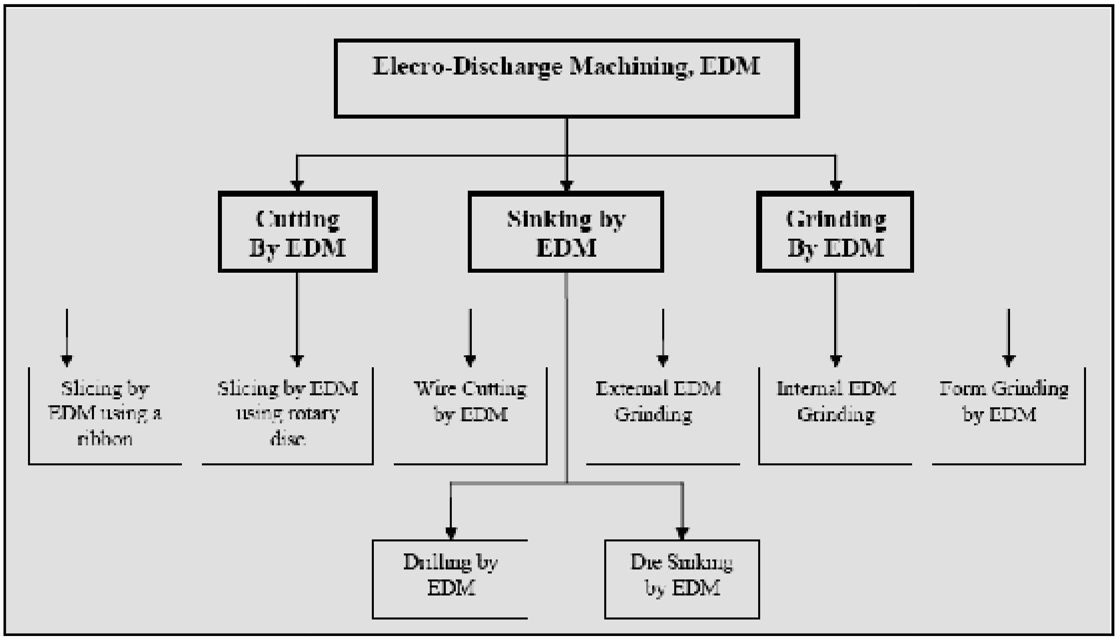


Figure 2.1: Classification of EDM processes [7]

2.2 EDM Process.

EDM machining is accomplished by the action of rapidly occurring electrical discharges, or sparks, which erode small pieces of metal from the workpiece. The cutting tool is an electrode that is shaped to the contour of the required cut. Both of the workpiece and the electrode are submerged in an electrically nonconducting (dielectric) fluid and connected to a dc power supply. The dielectric fluid functions as an insulator, coolant, and medium for flushing away debris from the tool and the workpiece, usually the dielectric fluid is consisting of mineral oil or kerosene,

Then the sparks travel through the nonconductive fluid to reach the workpiece, it were sent from the electrode to the workpiece at a rate of thousands per second, The electrode vaporizes the metal without ever touching the workpiece, which is by necessity made of electrically conductive material.

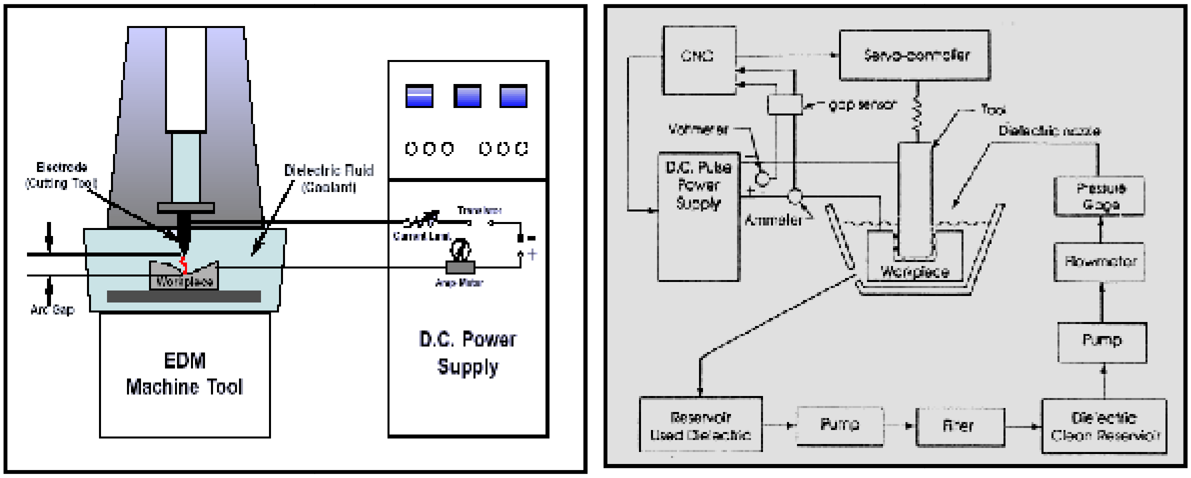
Although rates of metal removal are slower with electrical discharge machining than with other commercial machining methods, the slower removal produces better surface finishes. Higher rates of metal removal are known to produce rougher finishes that have a molten and resolidified (recast) structure with poor surface integrity and low fatigue properties [4].

Generally the EDM-die sinking is used to produce blind cavities [6]. When blind cavities are required, a formed electrode is machined to the desired shape. Then, by means of electrical current the preformed electrode surrounded by dielectric fluid, reproduced its shape in the workpiece. A powerful spark causes pitting or erosion of the metal on both the anode (+) and cathode (-). This process is also called spark machining or spark erosion machining. The EDM process involves a controlled erosion of electrically conductive materials by the initiation of rapid and repetitive spark discharges between the electrode and workpiece which is separated by a small gap.

Figure 2.2 showed the EDM is accomplished with a system comprising two major components [8]:

i. Machine tool
ii. Power supply

The machine tool holds a shaped electrode, which advances into the work material and produces a high frequency series of electrical spark discharges. The sparks are generated by a pulse generator, between the tool electrode and the work material, submerged in a liquid dielectric, leading to metal removal from the work material by thermal erosion or vaporization.



(a) (b)

Figure 2.2: The (a) Illustration and (b) Schematic of Basic EDM System [8]

2.3 Design Considerations for EDM

In this topic the user should follow the design consideration for their guideline for run a better any EDM works. The general design guidelines for electro-discharge machining are as follows: [9]

i) Parts should be designed so that the required electrodes can be shapes properly and economical.
ii) Deep slots and narrow opening should be avoided.
iii) The surface finish specified should not be too fine for produce the economic production.
iv) To achieve a high production rate, the bulk of material removal should be done by conventional processes (roughing out).

2.4 Machining Parameter in EDM Die Sink

In EDM, the variables parameters are have great effects to the machining performances results especially to the material removable rate (MRR), electrode wear rate and surface integrity. There are two major groups of parameters that have been discovered and categorized [8]:

i) Non-electrical Parameters
- Injection flushing pressure
- Rotational of speed electrode

ii) Electrical Parameters
- Peak current
- Polarity
- Pulse duration
- Power supply voltage

There is no present EDM technology that can eliminate all redeposition, of material, although the pulse-type power supply is efficient and effective for minimizing remelt and recast and also for protecting the workpiece from heat-related deterioration [10]. There are some important parameters can be considered that affect the machining surface produce such as:

i) DC voltage
- This is determined by the width of gap between the electrode and the workpiece. A higher voltage creates a current and spark across wider gap.

ii) Current (A)
- The erosion rate varies with current, as does electrode wear. As the amount of current goes up, so does the workpiece erosion rate. Different electrode materials demonstrate different rates of erosion. For example, copper electrode erodes at a constant percentage of the workpiece material. Graphite, on the other hand, wears more rapidly upon an increase in current but its wear rate then declines and remains nearly constant.

iii) On-time (pulse time or t_i):

- The duration of time (μs) the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is controlled by the peak current and the length of the on-time.

iv) Off-time (pause time or t_0):

- It is the duration of time (μs) between the sparks (that is to say, on-time). This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut. Thus, if the off-time is too short, it will cause sparks to be unstable.

v) Arc gap (or gap):

- It is the distance between the electrode and the part during the process of EDM. It also called as spark gap.

vi) Duty cycle:

- Duty cycle is a calculated percentage equal to on-time divided by total time for the complete on/off cycle. Modem EDM power supplies control duty cycle and on-time, but not off-time. While on and off times are usually constant, duty cycle control allows machine flexibility to adjust these times to meet special situations such as a section or particle of material not as conductive as the overall workpiece.

vii) Intensity (I):

- It points out the different levels of power that can be supplied by the generator of the EDM machine. (I) represents the mean value of the discharge current intensity.

2.4.1 Electrode

All EDM electrode materials must possess certain properties in order to perform economically in any application in the machining [11]. The main property of electrode is electrical conductivity, however, other application depending to the material workpiece used. The function of an electrode is to transmit the electrical charges and to erode the work piece to the desired shape.

Commonly the material of electrode are made of tungsten, copper tungsten, silver tungsten, yellow brass, chrome plated materials, zinc alloys, tungsten carbide, copper, graphite, etc [11]. Copper electrodes have been used primarily in resistance capacitance circuits where higher voltages are employed. Graphite electrodes are commonly used in application requiring little tool wear and high material removal rate. Brass electrodes are mainly used in pulse type circuits because of their good machinability. Table 2.1 shows the details of electrode material selection.

However the material selection should be done carefully because the quality surface finish is largely influenced by the electrode selection material. Different electrodes have their own effect on machining characteristics. Some electrode have a high MRR but the other else have different characteristic depends on what material and tool used [11].

Electrode Material	Form	Wear ratio in finishing	Wear ratio in roughing	Relative cost	Machinability Rating
Graphite	Block,rod, tube,bar	5 : 1	To 100:1	Low	Excellent
Copper	Bar,rod,sheet,wire, tube,forging,stampings	1:1	2:1	Medium	Good
Copper-graphite	Blocks,rods	2:1	4:1	Medium	Fine
Brass	Same as copper	0.7:1	2:1	Low	Good
Zinc alloys	Cast, die casting	0.7:1	2:1	Low	Good
Steel	All forms	1:1	2:1	Low	Excellent
Copper tungsten	Bar,flats,shim stock,rod,wire,tube	3:1	8:1	Medium	Fair
Silver tungsten	Sintered	8:1	12:1	High	Fair
Tungsten	Wire,rod,ribbon	5:1	10:1	High	Poor

Table 2.1: Types of electrode material for EDM [11]

Based on the table above, copper tungsten is the best choice and widely used as an electrode material in EDM machining tungsten carbide workpiece. This material has good properties such as high dimensional accuracy, very good resistant, high melting point temperature and etc [2]. Very good resistant, that's mean the surface of the electrode will not be eroded easily, thus keeping the workpiece dimensional accuracy to a high level [2]. Copper tungsten also has good finishing surface produce that can give minimum defection to the machined surface than other electrode such as copper and brass [11].

2.4.2 Flushing Pressure

Flushing is important because it removes eroded particles from the gap for efficient cutting. Flushing also enables fresh dielectric oil flow into the gap and cools both the electrode and the workpiece. Improper flushing causes erratic cutting, thus prevents the electrode from cutting efficiently. It is then necessary to remove the attached particles by cleaning the workpiece. Dielectric fluid is used as flushing to assist in the removal process of particles from the work area hence giving better surface finish [12].

There are five types flushing fluid system EDM such as pressure flushing, suction flushing combine pressure and suction flushing, jet flushing, and pulse flushing [6].

2.4.3 Dielectric Fluid

Basic characteristics required for dielectric used in EDM are high dielectric strength and quick recovery after breakdown [12]. The dielectric fluid acts as an insulator between the electrode and the mold cavity. The selection of dielectric fluid will be based on the insulation properties of the fluid. Air is not a very good insulator but water based dielectric is the best. However, water has a few drawbacks such as [8]:

i. It causes rust especially to electrode and workpiece or machine itself.

ii. The electrical discharge separates the water into pure hydrogen and pure oxygen. In other words it is a very explosive pair.

Therefore, kerosene is good compromise then water based dielectric [8]. Where it has no rust problem and no dangerous gasses are produced with kerosene. The suitable dielectric is based on the type of materials and the processes that are made and used. Most dielectric media are hydrocarbon compounds known as kerosene, and water. The machines are equipped with a pump and filtering system for the dielectric fluid.

The functions and properties of dielectric fluid are [6]:

i. Remain electrically non-conductive until the required breakdown voltage is reached (i.e.: should have high dielectric strength)

ii. Act as an insulator until the potential is sufficiently high.

iii. Breakdown electrically in the shortest possible time once the breakdown voltage reached

iv. Carrying away the swarf particles (materials, decomposition products, hydrogen, carbon, bubbles)

v. The pressurized fluid flushes out the eroded gap particles and remove the particles from the fluid by causing the fluid to pass through a filter system

vi. The fluid cool the eroded particle between the workpiece and the electrode

vii. To form a dielectric barrier for the spark between the workpiece and the electrode

viii. Provide an effective cooling medium

ix. Good degree of fluidity

x. Be cheap and easily available

2.5 Tungsten carbide

Tungsten carbide (WC-Co) with 15% cobalt content will be used as a material workpiece in this project. Increasing the cobalt content in this material will increase the hardness of the WC-Co. Table 2.2 shows the composition and properties of WC-Co materials with increasing cobalt content.

Actually WC-Co has a compressive strength greater than any other metal or alloy and is three times more rigid than steel. Abrasion resistance is up to 100 times greater than steel. Thermal expansion is less than one-half that of steel, and tungsten carbide resists thermal shock and oxidation temperatures up to 1200°F (648.89°C) [13].

Composition of Tungsten Carbide		Density,	Rockwell Hardness,	Vickers Hardness	Transverse Rupture
% of WC	% of Co	g/cm^3	R_A	kg/mm^2	Strength, psi
100	-	15.7	92-94	1,800-2,000	43,000-71,000
97	3	15.1-15.2	90-93	1,600-1,700	142,000-170,400
95.5	4.5	15.0-15.1	90-92	1,550-1,650	170,000-199,000
94-94.5a	5.5-6	14.8-15.0	90-91	1,500-1,600	277,000-256,000
94-94.5b	5.5-6	14.8-15.0	91-92	1,600-1,700	199,000-227,000
91	9	14.5-14.7	89-91	1,400-1,500	213,000-270,000
90	10	14.3-14.5	88.5-90.5	1,350-1,450	220,000-277,000
89	11	14.0-14.3	88-90	1,300-1,400	227,000-284,000
87	13	14.0-14.2	87-89	1,250-1,350	241,000-298,000
85	15	13.8-14.0	86-88	1,150-1,250	256,000-312,000
80	20	13.1-13.3	83-86	1,050-1,150	284,000-369,000
75	25	12.8-13.0	82-84	900-1,000	256,000-384,000
70	30	12.3-12.5	80-82	850-950	-

Table 2.2: Composition and Properties of WC-Co Materials with Increasing Cobalt Content [13]